Evaluation and review of potential impacts of mountain pine beetle infestation to composite board production and related manufacturing activities in British Columbia

Ian D. Hartley and Sorin Pasca

Mountain Pine Beetle Initiative Working Paper 2006–12

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Abstract

During the past decade, the mountain pine beetle has extensively attacked the lodgepole pine forests of British Columbia. The forest products industry, along with government initiatives, has been challenged to harvest and process the beetle-killed timber across various stages of decay and time since death. The primary uses of the logs, as with non-beetle–killed timber, have been for the production of dimension lumber and composite board manufacturing (i.e., oriented strand board, plywood, particleboard and medium-density board). This report presents a summary of past research efforts that have investigated the impact of similar large-scale beetle epidemics elsewhere in North America on composite board production and manufacturing. This study also appraised the potential impact of the current British Columbia infestation on the provincial composite board industry. A survey was conducted with researchers and mill personnel in the province. Three key attributes were identified from the survey that are important for composite board manufacturing: moisture content, blue stain and glueability. The results are summarized in this report.

Key Words: mountain pine beetle, *Dendroctonus ponderosae*; lodgepole pine; *Pinus contorta*; composite boards; engineered wood products; oriented strand board; particleboard; medium density board.

Résumé

Au cours de la dernière décennie, le dendroctone du pin ponderosa a causé des dommages considérables dans les forêts de pins tordus en Colombie-Britannique. L'industrie des produits forestiers, ainsi que diverses organisations gouvernementales, ont eu la lourde tâche de récolter les arbres tués par le dendroctone et de transformer du bois à divers stades de décomposition et mort depuis plus ou moins longtemps. Ce bois, tout comme celui provenant d'arbres qui n'ont pas été tués par le dendroctone, a principalement servi à produire des sciages à dimensions spécifiées et à fabriquer des panneaux composites (c.-à-d., panneaux de grandes particules orientées, contreplaqués, panneaux de particules et panneaux de fibres à densité moyenne). Ce rapport présente un résumé des efforts de recherche qui ont été déployés dans le passé lors d'infestations massives similaires de ce ravageur dans d'autres régions de l'Amérique du Nord et qui s'intéressaient à l'impact des infestations sur la production et la fabrication de panneaux composites. La présente étude a également évalué l'impact potentiel de l'infestation qui sévit actuellement en Colombie-Britannique. sur l'industrie des panneaux composites de la province. Une enquête a également été effectuée auprès des chercheurs et du personnel d'usine en Colombie-Britannique. Elle a permis de cerner trois attributs clés importants pour la fabrication de panneaux composites : le degré d'humidité, le bleuissement et l'aptitude à l'encollage. Les résultats sont résumés dans le présent rapport.

Mots clés : dendroctone du pin ponderosa (*Dendroctonus ponderosae*); pin tordu (*Pinus contorta*); panneaux composites; produits de bois d'ingénierie; panneau de grandes particules orientées (OBS); panneau de particules; panneau de fibres à densité moyenne (MDF).

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Introduction

The current mountain pine beetle (*Dendroctonus ponderosae* Hopkins) outbreak on lodgepole pine (*Pinus contorta* var. *latifolia*) in British Columbia began more than a decade ago. The volume of beetle-killed wood increased exponentially over this period of time; today, it is about 400 million m^3. Although the major British Columbia forest product companies currently harvest green timber, it is possible that in the short to long term, the majority of available timber will be beetle-killed pine. Thus, the use of beetle-killed wood for forest products will increase. Hundreds of million of cubic meters of beetle-killed trees are now standing in British Columbia forests. The shelf life of the affected timber is, from the dimension lumber producers' perspective, about 5 years. The effective shelf life of the beetle-killed timber could be prolonged if other wood products are considered.

The only way to fully exploit the large timber volume is to manufacture forest products other than dimension lumber, and develop wood-related products that can effectively use beetle-killed wood. The use of beetle-killed timber for alternative products will not be possible without a comprehensive knowledge of the physical and chemical characteristics of the beetle-killed resource and the impact that these characteristics would have on a manufactured product's structural properties.

Beetle-killed timber and its physical and mechanical properties have drawn the attention of many researchers through the years. In the early 1940s, work by Chapman and Scheffer (1940) examined the toughness of wood that had been severely affected by stain fungi. After the first significant beetle outbreak in the southern United States in the 1960s, the number of studies on the deterioration and use of the beetle-killed timber increased. Some of the studies focused on a single physical or chemical element. Others developed datasets describing the multiple characteristics of the dead wood and their implications for manufacture of a range of products.

One purpose of this study is to highlight the key physical properties of beetle-killed wood derived from studies in the United States and Canada over the past decades, with a focus on attributes that may impact the composite industry. Another purpose of the study was to determine the perspective from industry (manufacturers of composite boards) toward the use of beetle-killed pine. A questionnaire survey was developed and sent to research and mill personnel in British Columbia, and on-site interviews were conducted with respondents. The main purpose of the survey was to highlight key beetle-killed wood attributes that would be an asset and/or a liability for the manufacturing of composite products.

Physical properties

The ability to use wood for different products is based largely on the wood's physical properties. There are recent reports by Lewis and Hartley (2005) and others that highlight key physical properties of beetle-killed wood. This section details those factors and attributes that pertain primarily to composite board products.

Moisture content

The moisture content of wood, oven-dry basis, impacts many areas of processing. Beetle-attacked lodgepole pine can lose about 40% moisture in the outer sapwood within a couple of months following death (Reid 1961). Within one year, the moisture content can drop below fiber saturation point (moisture content less than 30%). There was also a correlation made between blue-stained lodgepole pine and the moisture loss of standing beetle-killed southern pine trees, where 50% more moisture was lost in the standing trees compared to trees that were felled and on the ground (Barron 1971). Looking at the use of dead lodgepole pine for power poles, it was found that, within the upper portions of the stem, the lower moisture content impedes the growth of wood decay fungi (Tegethoff et al. 1977). Researchers also studied the rate of decrease in moisture content in relation to the time since the trees were attacked by beetles (Dobie and Wright 1978, Lowery and Hearst 1978).

The incidence of lower moisture content in the beetle-killed wood was identified as an important factor in providing lower transportation and lower drying costs (Maloney et al. 1978). Differences in drying schedules between beetle-killed wood and green timber were examine, as were the implications associated with over-drying the beetle-killed wood (Lowery and Hearst 1978).

The rapid loss of moisture below the fiber saturation point in sapwood, which is closely related to the development of checks and splits (Nielson and Wright 1984), has caused problems with the quality of flakes (or strands) used in composite boards and with maintenance of cutting tools.

Specific gravity

Specific gravity (SG), or relative density, is directly related with most wood mechanical properties, and a correlation is needed for assessing strength for specimens having different SG (Sinclair et al. 1979b). Density losses due to decay for white pine with deep checks and no twigs were found to be as much as 14% (Maloney et al. 1978); felled trees in direct contact with the ground lost twice the wood substance after 6 months (Baron 1971). At one year after death, the specific gravity of beetle-killed southern pine was 60% (Walters and Weldon 1982b) of green timber, although until 90 days after death, the average weight was higher than that of green trees (Walters 1982), probably due to presence of blue-stain fungi.

Toughness

A major impact on physical property changes within mountain pine beetle-killed wood since time of death was toughness. Nielson (1986) noted that toughness is the only strength characteristic of the wood actually affected by blue stain. Chapman and Scheffer (1940) reported a drop in toughness of 30% for wood that was severely affected by staining fungi (Sinclair et al 1978); Findlay and Pettifor (1937) considered blue-stain infection a liability only when high-toughness lumber was required (Levi and Dietrich 1976). Carey (1977) was cited as finding a reduction in toughness by 53% in dead pine (Troxell et al. 1980). The loss in toughness over the first 12 months approached 40% for southern pine specimens (Sinclair et al. 1979a), and 9% after two months for shortleaf pine (Sinclair et al. 1978). It seems that moisture content was directly responsible for the decrease in toughness, as butt logs were found to have a higher loss in toughness compared to upper logs (Sinclair et al. 1979a), and it is known that moisture content is lower in upper portions of the beetle-killed tree.

Strength

Mechanical properties of beetle-attacked trees were apparently insensitive to blue-stain infestation. The strength test values obtained from southern pine specimens at one year since beetle attack were not significantly different than those from green, unattacked material. However, the modulus of rupture (MOR) did show a reduction of 19% after 20 months since death, whereas the modulus of elasticity (MOE) decreased 11% after 12 months since death. The loss in compressive strength was 7% after two years since death (Sinclair et al. 1979b). Carey (1977) found that the strength properties decreased about 10% in dead pine (Troxell et al. 1980). Most of the physical and mechanical properties (including strength characteristics) of beetle-killed lodgepole pine with tight bark were found to be quite similar to those of green timber (Lemaster et al. 1983), although Walters (1982) pointed out that southern pines had shown a reduction of 12% in MOR and 13% in MOE after one year since death. It was also shown that MOE remained unchanged after 90 days since death (Walters 1982).

Permeability

Only a few studies have been completed on the permeability of beetle-killed timber. Studies on ponderosa pine noted an increase of up to three times in chemical uptake when dead wood is considered (Troxell et al. 1980). Lindgren and Scheffer's (1939) findings showed an increased percentage of absorption and, related to that, a high rate of penetration of liquids in the blue-stained wood (Troxell et al. 1980). An inverse relationship between moisture content and permeability due to blue-stain fungi infection was observed by Lindgren and Scheffer (1939), suggesting a degradation of ray parenchyma cell walls (Levi and Dietrich 1976). Seifert (1964) found losses of 7% cellulose and 3% to 4% hemicellulose in blue-stained timber (Troxell et al. 1980), which could be related to changes in permeability and/or toughness. Recent work by Woo et al. (2005) showed that the permeability of sapwood of beetle-killed wood is greater than that of non-infected sapwood, whereas non-infected heartwood is more permeable than is the heartwood of beetle-killed wood.

Wood products

Since there was a large amount of dead wood as a consequence of beetle attacks, research efforts have focused on use of beetle-killed timber for a range of products. From lumber to plywood, and from power poles to oriented strand board, efforts were directed toward a better understanding of how beetle-killed wood would affect different products.

A number of variables need to be taken into account. Over the years, a range of conventional products has been studied, in terms of how well beetle-killed wood is suited for the manufacture of these products. Other research focused on less common products at the time: power poles (Tegethoff et al., 1977), pallets, round timbers, laminated wood (Troxell et al. 1980), panel (Christophersen and Howe 1979; Troxell et al. 1980; Walters and Weldon 1982a), and fuel (Ince 1982). An important part of the research interest was directed towards the use of dead wood for pulp and paper. Dry checks and sap rot are the most important causes of loss in lumber grade (Dobie and Wright 1978; Carr 1978; Sinclair and Ifju 1979; Walters and Weldon 1982a; Plank 1984; Lowell 2001). As a result, attention was directed towards researching the manufacturing of those products listed above that avoided these characteristics of dead timber and that used small pieces of wood that could be incorporated into composition boards.

Plywood and Veneer

The statement about there being insufficient evidence for justifying use of beetle-killed pine in production of plywood has merit (Levi et al. 1976), although many studies have shown that there was no significant difference in veneer recovery between green and dead timber, especially when the affected trees are used immediately after attack (Walters and Weldon 1982a). However, after 3 years since death, veneer recovery from the dead material was 30% less than that from green trees (Snellgrove and Ernst 1983). Sapwood was in poor condition and tended to break up during the peeling process (Reiter 1986). Among the advantages of using beetle-killed lodgepole pine for veneer was the potential of peeling small logs on a core lathe (Fahey 1980). Some technological adjustments were needed in the 1980s, including new lug geometry for lathe chucks, which avoided the splitting of the blocks, an electronically assisted corrected knife angle, and a new concept of peeling with a spindleless veneer lathe (Reiter 1986). The reduced drying time for beetle-killed timber was considered an asset for savings in energy consumption (Snellgrove and Ernst 1983). To avoid over-drying, the beetle-killed wood should be segregated from green timber for drying schedules (Walters and Weldon 1982), as it needs only half the time required to dry green material (Lowery and Hearst 1978).

Oriented Strand Board

The oriented strand board (OSB) industry represents one of the most flourishing wood-related activities in the last 20 years. Although the board product was developed from green wood, the current mountain pine beetle epidemic in British Columbia presents new challenges. The use of beetle-killed lodgepole pine for OSB is of current research interest.

There were studies on fungal susceptibility of panels which included samples of southern pine OSB for both tests on decay resistance and on susceptibility to surface mold growth (Laks et al. 2002). The results found for green-pine OSB were encouraging, compared with those for aspen OSB, and the experiments could be repeated for beetle-killed pine OSB.

The same approach could be done for testing swelling thickness and its relationship to internal bond strength loss, similar to the study made on two types of southern pine commercial OSB. Curled/folded flakes seemed to be directly responsible for losses in internal bond strength (Wu and Piao 1999). Species mix and species distribution also had an effect on the layer characteristics of OSB when southern pine and aspen were compared (Wang and Winistorfer 2000).

Other Composite Boards

Some authors have considered manufacturing particleboards from forest residues to be inefficient due to the associated logging costs (Fahey 1980). However, others have mentioned that the costs are similar for making particleboard from beetle-killed timber or from green trees, even though some exceptions should be considered, such as flakeboard production (Maloney 1981). Studies showed an improved quality of particleboard when adding blue-stained timber into the furnish (Kelly et al. 1982).

One of the most important aspects of using beetle-killed timber for composite board is the possibility of eliminating types of degrades found within the logs—such as deep checks, sap stain and pockets of decay—which impede use of the timber for lumber and plywood (Maloney et al. 1978).

A study was released in 1977 on the suitability of dead white pine and lodgepole pine for composite boards. The quality of wood particles seemed to be the key factor in limiting production of quality composite board as the geometry of flakes affects the product's physical properties and internal bond strength characteristics. Other liabilities in using beetle-killed wood were an increase in the amount of fines produced, the need for extra screening capacity and extra maintenance for cutting knives, the decrease in slenderness, and the tendency of the flakes to become folded (Maloney et al. 1978; Maloney 1981).

Nevertheless, except for structural board, the studies showed insignificant differences between particleboard produced from beetle-killed wood and those produced from green wood. As well, the internal bond strength for phenolic-bonded particleboard from beetle-killed lodgepole pine was found to be higher than that from green timber (Maloney et al. 1978). Adjusting the particle mixture to include 25% material from beetle-killed timber (3 months since death) increased both MOR and MOE compared to the 100% green-wood mixture; the water-soak test results were better (Kelly et al. 1982) as well. It appeared that beetle-killed wood particles can produce glue bonds as good as or better than those in non-beetle–killed wood (Troxell et al. 1980). As the resin response could be related to chemical properties, pH was tested and determined to be essentially unchanged for the beetle-killed wood (Maloney et al. 1978). However, solubility in sodium hydroxide decreased to 33% for beetle-killed wood at 5 years since death (Troxell et al. 1980).

In terms of linear expansion of the board, the findings showed that test results were lower for fiberboard made from beetle-killed lodgepole pine than for those made from green wood. Test results were also lower for board made from white pine than for those made from lodgepole pine (Maloney et al. 1978). However, when beetle-killed southern pine was used for particleboard at 30 months since death, linear expansion exceeded specifications. Test results did improve when green material was added to furnish mixtures (Kelly et al. 1982).

In summary, some characteristics of the composite board made from beetle-killed wood with a slight increase in small particle size showed good internal bond test values, acceptable values for MOR and MOE, and a slight increase in thickness swelling and water absorption (Troxell et al. 1980). Structural board possessed lower internal bond strength due to a poorer-quality flake, but exhibited good test results for linear expansion (Maloney et al. 1978).

Beetle-killed wood characteristics – research and mill perspective

Surveys have been used in the past to gather information from mill personnel and others as to their knowledge of pine beetle outbreak. In the United States, when more than 600 timber buyers were questioned about their plan to purchase and use beetle-killed southern yellow pine 30 years ago, they expressed confusion and had a lack of technical information on the topic (Levi et al. 1976). Therefore, with the situation in British Columbia and the issues presented in the previous sections, it was important to consider the research and mill personnel perspective with operations in the province. A survey was developed and sent to those two groups.

Background

In a study regarding the wood-use potential of beetle-killed lodgepole pine (*Pinus contorta*), 13 products were identified. Key evaluators were then defined, including: appearance, bending strength (MOR), stiffness (MOE), toughness, specific gravity, checking, and treatability, among others. Each key evaluator was assigned a weighting factor (1, 2 and 3; with 1 being less important and 3 the most important), based on the combined judgment of investigators concerning the importance of the property in product use (Lemaster et al. 1983).

Although the composite board were not among the selected products in that study, it was interesting that, at the beginning, all wood properties (key evaluators) were considered liabilities for product use (ranging from 1 to 3), but at the end, after a weighted index value was determined through laboratory tests for each evaluator (compared with a 100% index value for live lodgepole pine), some of the

properties proved to be assets rather than liabilities. For example, the index for "ease of seasoning" was 135% for dead lodgepole pine with tight bark and 148% for dead lodgepole pine with loose bark. "Positive" results were also found for 'gluability' (103% for dead lodgepole pine with loose bark), stiffness (MOE) (110% for dead lodgepole pine with tight bark) and 'treatability' (135% and 115% respectively).

Indicators which should be weighted when doing assessments on the suitability of the beetle-killed timber for manufacturing of composite board should include: moisture content, level of blue stain, gluability capacity, specific gravity, permeability, strength properties, and toughness. In most cases, the potential users of dead wood have little information about cue weighting and the level of uncertainty in their judgments (Alderman et al. 2004). However, recent studies have shown that some characteristics of the beetle-killed wood might be useful from various perspectives. The degree of importance for each of these evaluators should be clearly defined, especially in distinguishing liabilities from potential assets.

As noted in the previous sections, the loss of moisture content in the beetle-killed lodgepole pine seems to have many implications in the manufacturing of composite board. On the one hand, lower moisture content in dead timber leads to lower transportation costs and lower drying costs (Maloney et al. 1978); on the other hand, the difference in drying schedules between dead and live timber has implications for over-drying (Lowery and Hearst 1978). The problems associated with the quality of flakes (strands), or the quality of veneer sheets, and those associated with special maintenance of cutting tools, are also related to reduction in moisture content and its consequences.

Blue-stain fungi, as non-decay fungi, have almost no impact on structural characteristics of the beetle-killed wood. Moreover, sapstain has little effect on milling properties or resin compatibility for composite board (Maloney et al. 1978), and there is no evidence that blue-stained pine is harmful for humans or in contact with food stuff (Troxell et al. 1980). Nevertheless, the key impact of staining fungi seems to be in the alteration of the external appearance of the wood products, although some customers may regard this 'disfigurement' as an asset rather than a liability.

Gluing problems were initially reported in regards to structural flakeboard made from beetle-killed timber. Flakes made by drum flaking were wider than normal and tended to become curled and/or folded, resulting in a lot of surface area remaining uncoated by resin (Maloney et al. 1978). Studies on OSB examined the impact of the number of fines produced when flaking dead/dried material on the gluing characteristics of the board. When used for plywood or laminated beams and joists, beetle-killed wood was assessed as an asset rather than a liability due to its having good glue-bonding characteristics, although a higher absorption rate did lead to increased glue consumption (Troxell et al. 1980).

Questionnaire and interview design

Among various factors contributing to making decisions on use of beetle-killed timber for manufacture of composite board, three key attributes were identified: moisture content, blue stain, and gluability capacity. Most related industry issues and, consequently, most related research projects deal with these three main characteristics of the infested timber.

The interviews conducted in this study were with researchers and mill personnel based in British Columbia. A questionnaire was sent to 15 researchers and 15 mill personnel, with only four and five responses completed, respectively. Once the questionnaire (see Appendix) was returned, a follow-up site visit was conducted.

Each interviewed researcher or mill personnel was provided with the same set of indices of three scaled wood characteristics representing potential indicators in assessing suitability of beetle-killed timber for composite board (plywood, OSB and MDF). Three wood attributes were chosen for assessing liability and/or asset of using beetle-killed wood: moisture content, blue stain, and gluability capacity. The overall suitability of beetle-killed wood for the products was also evaluated. The suitability indices for attributes were ranked from –5 (the least-suited attribute, as a liability) to +5 (the most-suited attribute, as an asset), where the non-beetle–killed wood was considered a reference point (index of 0). It has been found that when assessing suitability of the dead wood for products,

judgments vary depending on knowledge of the topic and on the perspective the interviewee used when doing the assessment.

Data analysis

Three non-parametric statistical analyses were performed for each of the following situations: overall suitability for moisture content, overall suitability for blue stain, and overall suitability for gluability capacity. The assessment model used was:

$$A = b_0 + \sum_{i=1}^{n} (b_i X_i) + \beta$$

where:

A = assessment (suitability for a certain product)

b_0 = regression constant (intercept)

b_i = cue regression coefficient (cue weight)

X_i = cue (wood characteristic, property)

ß = error

The indices range from –5 to +5 as indicated above.

The results from the statistical analysis of the questionnaires from researchers and mill personnel are presented in Table 1.

Table 1. Rank responses in terms of overall suitability and corresponding ranks with moisture content, blue stain and gluability.

Moisture Content

	Overall Suitability		Moisture Content		Xi*Yi	Xi^2	Yi^2	Sxy	Sxx	Syy	Correlation	
	Index	Rank (x)	Index	Rank (y)							rs	Critical rs
R1	-2	4.5	-4	8	36	20.3	64	-8.6	59.2	54	-0.152	0.6
R2	-1	2	-3	5	10	4	25					
R3	-4	7.5	-4	8	60	56.3	64					
R4	-2	4.5	-3	5	22.5	20.3	25					
M1	-5	9	-3	5	45	81	25					
M2	-3	6	-4	8	48	36	64					
M3	-1.5	3	0	2	6	9	4					
M4	0	1	0	2	2	1	4					
M5	-4	7.5	0	2	15	56.3	4					

Blue Stain

	Overall Suitability		Blue Stain		Xi*Yi	Xi^2	Yi^2	Sxy	Sxx	Syy	Correlation	
	Index	Rank (x)	Index	Rank (y)							rs	Critical rs
R1	-2	4.5	-1	4.5	20.3	20.3	20.3	-4	59.2	52.8	-0.072	0.6
R2	-1	2	-1	4.5	9	4	20.3					
R3	-4	7.5	-2	8	60	56.3	64					
R4	-2	4.5	0	1.5	6.8	20.3	2.3					
M1	-5	9	-1	4.5	40.5	81	20.3					
M2	-3	6	-1	4.5	27	36	20.3					
M3	-1.5	3	-2	8	24	9	64					
M4	0	1	0	1.5	1.5	1	2.3					
M5	-4	7.5	-2	8	60	56.3	64					

Gluability

	Overall Suitability		Gluability		Xi*Yi	Xi^2	Yi^2	Sxy	Sxx	Syy	Correlation	
	Index	Rank (x)	Index	Rank (y)							rs	Critical rs
R1	-2	4.5	0	4	18	20.3	16	-5.1	59.2	58	-0.087	0.6
R2	-1	2	1	2	4	4	4					
R3	-4	7.5	-4	9	67.5	56.3	81					
R4	-2	4.5	2	1	4.5	20.3	1					
M1	-5	9	-1	6	54	81	36					
M2	-3	6	-2	7	42	36	49					
M3	-1.5	3	-2.5	8	24	9	64					
M4	0	1	0	4	4	1	16					
M5	-4	7.5	0	4	30	56.3	16					

Results

Researchers

Five researchers were involved in studying the implications of using beetle-killed timber for manufacture of composite products. Although no statistical correlation was found, there was a tendency toward a positive correlation between suitability indices from a 'researcher's perspective'; that is, as the 'moisture content' suitability index decreases, the overall suitability index decreases as well, or as the moisture content index increases, the overall index increases. The same trend occurs with the correlation between overall suitability and blue stain and gluability capacity. It is obvious that, as most of the research projects address these three wood characteristics, the suitability of the infested timber for composition board is seen to be directly related to them.

Examining the indices with the average index of –3.5, it can be inferred that the "...negative impacts of low moisture content far outweigh any benefits from reduced energy consumption to dry the strands or veneer" (Interview Participant 2005). This is a consistent opinion among researchers. The reduced recovery of full veneer sheets and the increased amount of fines are the big concern in using beetle-killed timber for plywood and OSB, respectively.

The researchers' responses referring to the blue-stain indices (average index –1) were similar to those referring to moisture content, although the weight values indicate that this "...cosmetic..." (Interview Participant 2005) issue is considerably less important than moisture content.

In terms of both moisture content and blue stain, the suitability indices show that timber's infestation is regarded as a liability from the researcher's perspective. There is no doubt that these two characteristics of beetle-killed wood affect the process for manufacture of composite board.

The indices regarding gluability vary; however, the correlation coefficient is the closest to the critical value. The indices range from strong liability (index –4) to fair asset (index +2), that is, researchers agree that working on improving this index will lead to an improvement of the overall suitability index, although further research is needed to clarify this issue and to better understand the implications of gluability.

Some of the current research interests addressing the issue of suitability of beetle-killed wood for composite board are (from Interview Participants):

- the need to upgrade the mill visual grading system, which still sees blue-stained veneer as low-grade defective veneer;
- completing the information regarding the properties of blue-stained wood, in order to change customer perception, especially in Japanese markets;
- liquid and gas permeability of the beetle-killed wood and products;
- water absorption and thickness swell of OSB made from beetle-killed wood;
- changes in chemical composition of the blue-stained wood; and,
- bondability of beetle-killed wood for manufacture of MDF and particleboard.

Mill personnel

Based on the mill personnel responses and running the same statistical tests (Table 1), there was no agreement between overall suitability indices and indices by each of the three beetle-killed wood characteristics—indicating the diversity of factors that are taken into account by mill personnel when it comes to assessing suitability of dead timber for products.

Not only were wood properties weighted, but also factors belonging to specificity of each technological process. Some mill personnel have raised the issue of changing moisture content of the air used in the heating process when dried beetle-killed bark is used in place of 'green' bark (Interview 2005), whereas others referred to the increased bulk density in strand-holding bins, which impacts operational issues (Interview 2005).

At an OSB operation, the fines-screening system runs at the upper limit and the surplus of fines created even more problems related with the disposal of them (Interview 2005). Using beetle-killed wood for a certain product requires that equipment settings be adjusted in order to cope with a

different technological situation. However, running only beetle-killed wood is almost impossible as most wood arrives at a mill site as mixed loads, and any attempt to sort leads to increased costs.

Although mill respondents knew that the low moisture content causes logs to develop checks that are considered a disadvantage for manufacturing veneer, some of them weighted the moisture content at the same value as the green timber (index 0), as they have experienced using beetle-killed wood immediately after harvesting, which considerably reduces split development. In one specific case, the low recovery was due not to moisture content but to poor storage management of the logs (Interview 2005).

A respondent gave an example with regards to industry's capacity to confront new challenges incurred and to adjust its technological process accordingly: "In (our business) the raw materials are residuals of the sawmilling process. As the mills process beetle-killed wood, (our business) has no choice but to process the fibre as it receives it. The pH of the materials may change, but as the mill has no influence on its raw materials, resin chemistry is used to compensate."

It has also been found that moisture content and blue stain have no adverse effect on MDF production or process (Interview 2005).

Research and mill personnel
Results of running the statistical tests for all respondents (researchers and mill personnel altogether) proved ambiguous, as the correlation coefficient values approach zero; that is, there is no correlation between the overall suitability indices of the beetle-killed timber for composite board and similar indices related with the three wood characteristics considered (moisture content, blue stain, and gluability). It is even harder to assess infested wood in terms of degree of liability or asset. Because of the specificity of each product, the technological processes involved, and the various perspectives considered in approaching the issue, there is a great variability in assessing usability of dead wood for wood products. The lack of consistency among responses indicates need for better coordination between research centres and industry operations.

Discussion

The reluctance of the public and timber buyers to use wood products manufactured from beetle-killed timber indicates that the main goal of research in this field of study should be to scientifically prove that wood products from beetle-killed wood maintain much of the physical and mechanical integrity of products derived from green wood.

There were a number of studies that address this problem, particularly in the last 30 years. From the southeastern and northwestern US, beetle outbreaks have affected millions of cubic meters of different species of pine. United States research centres that evaluate the utility of beetle-killed timber for different products provided experimental results that were confusing in terms of suitability of beetle-killed wood for any specific product. Most of the studies concluded that the physical characteristics and properties found for a certain property were lower when beetle-killed wood was used. What should have been expressed by the studies was whether the studied characteristic met or did not meet industry standards or specifications.

Taking into account the current situation in British Columbia, where a huge amount of dead timber awaits use, research efforts should be directed toward the development of an integrated grid of assessments for beetle-killed wood in terms of suitability for certain products. This will help both producers and customers to better understand the importance of different physical characteristics associated with beetle-killed wood, as well as the level (i.e., grade and/or quality) to be attained by each of these characteristics in accordance with established specifications for each product.

Current and past mountain pine beetle outbreaks in the province have resulted in significant volumes of beetle-killed lodgepole pine timber across a range of deterioration conditions. From grey-attack stage timber in the Chilcotin (20 years since attack) to red-attack stage timber in the Cariboo (2 years since attack), all grades of timber in terms of level of decay are distributed within a relatively contiguous and accessible area.

There are some physical properties of beetle-killed wood that have been studied and that are, or could be, related to the product characteristics (properties) required to meet industry standards. For example, it is well known that the specific gravity of wood influences the strength of a structural board. The studies could prove that when the specific gravity falls below a certain value, the structural board fails the standard tests for strength. An assessment of specific gravity could be conceived within an index system or group of classes, and the timber could be marked accordingly for log quality. Attainment of classes would provide the threshold standard for a specified product.

Recommendations

The survey results show moisture content as being an issue of common interest from the researchers' point of view, but this is not necessarily a position shared by all mill personnel. This indicates a disconnection within the two groups' priority ranking of the three key attributes. However, based on the discussion presented in the report, potential areas for future research include:

- the development of methods for sorting timber by moisture content directly in the woods, which would reduce costs that would occur inside the mill and improve the kiln-drying process. Beetle-killed wood has lower moisture content than green wood, and inappropriate drying schedules can result in over-drying that can prove detrimental for certain products by increasing the level of defects and degrades. Currently, this issue has become extremely important, as there is large variation in terms of degree of deterioration, even within timber from the same forest area.
- the determination of those physical properties of beetle-killed wood that can be strongly related with the mechanical characteristics of various wood products. It has already been found that the decrease in specific gravity is directly related with a drop in mechanical test values of the products. Although most of the studies referred to the correlation between permeability and the rate of absorption or penetration of liquids, no connection has been made between wood permeability and mechanical properties of the specified products. Testing specific gravity and permeability could represent expeditious means to assess suitability of beetle-killed timber for manufacture of certain forest products.
- the determination of means by which the characteristics of beetle-killed timber impact the toughness strength property of various wood products. A group of directed studies is needed to clarify this issue in terms of the degree to which loss of moisture affects toughness, or what other possible transformations suffered by dead wood could affect toughness, and how toughness affects product properties.
- the importance of using mixtures of beetle-killed and green wood in order to improve quality of composite board made from beetle-killed timber. There exist findings (Kelly et al. 1982) stating that physical and mechanical properties of the composite board from beetle-killed wood increase when different proportions of green wood are added to the mixture of furnish. It is important to know which ratio is needed to attain different specifications for products, and how this ratio is influenced by timber having different degrees of deterioration. Also, it would be interesting to determine if beetle-killed wood from lodgepole pine added to mixtures of two or more different wood species improves product quality.
- the behavior of beetle-killed wood when used for OSB. There have been a number of recent studies on OSB that have dealt with the properties of this relatively new product. Use of less-suited wood species for the core layer, fungal susceptibility, decay and mold resistance tests are some of the areas studied.

Conclusions

As found in this study and others, information exists on the physical properties of the wood from mountain pine beetle-killed trees, but there is a lack of information on composite-board products produced from that wood. There is also need for research on composite products that can be developed from beetle-killed wood. It was clear from the questionnaire and on-site interviews that a better understanding of the relationship between attribute indices and composite-board products is necessary. Also, those attribute indices that were highlighted in this study and are related to composite board products were not similar between the two groups. A common understanding should be accomplished through the development of stronger research programs and improved information flow between mill operations and researchers.

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Appendix – Questionnaire

Wood product: OSB / Plywood / MDF

Moisture content

The loss of moisture content in the beetle-killed lodgepole pine seems to have many implications in manufacturing wood products. On the one hand lower moisture content in dead timber leads to lower transportation costs and lower drying costs. On the other hand, the difference in drying schedule between dead and live timber has implications in over drying. The problems associated with the quality of the flakes (strands) used in composition boards or the quality of the veneer sheets and those associated with special maintenance of the cutting tools are also related with the moisture content.

1. Have you ever taken into account the moisture content of the beetle-killed lodgepole pine as a potential quality attribute when it needs to make decisions about using dead wood for OSB / Plywood / MDF?

Yes	No

2. If 'YES', taking into account the circumstances described above and based on other knowledge you have on this topic, how do you assess the degree of importance the moisture content has on using beetle-killed timber for OSB / Plywood / MDF ?
Please consider the live wood as a reference point.

-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5

Liability <<< --------- << --------- < No importance > --------- >> --------- >>> Asset (Live timber)

3. Could you describe the reasons you had in your selection? Which are the product's attributes mainly affected by the moisture content? (e.g. strength, recovery, etc.)

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Wood product: | OSB / Plywood / MDF |

Blue stain

Blue stain fungi, as non-decay fungi, have almost no impact on structural characteristics of the beetle-killed wood. Moreover, sapstain has little effect on milling properties or resin compatibility for composition boards, and no evidence have yet been found that blue stained pine is harmful for humans or in contact with food stuff. However, some toughness loss was reported even after the first signs of blue stain. Nevertheless, the key impact of staining fungi seems to be in the alteration of the external appearance of the wood products, although some customers regard this 'disfigurement' as an asset rather than liability.

1. Have you ever taken into account the blue stain of the beetle-killed lodgepole pine as a potential quality attribute when it needs to make decisions about using dead wood for OSB / Plywood / MDF?

Yes	No

2. If 'YES', taking into account the circumstances described above and based on other knowledge you have on this topic, how do you assess the degree of importance the blue stain has on using beetle-killed timber for OSB / Plywood / MDF?
Please consider the live wood as a reference point.

-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5

Liability <<< --------- << --------- < No importance > --------- >> --------- >>> Asset
(Live timber)

3. Could you describe the reasons you had in your selection? Which are the product's attributes mainly affected by the blue stain? (e.g. strength, recovery, etc.)

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Wood product: OSB / Plywood / MDF

Gluability

The gluing problems were firstly reported for the structural flakeboards made of beetle killed timber, because the flakes made by drum flaking were wider and tended to become folded, a lot of surfaces remaining uncoated by resin. Recent studies on OSB added to this problem the fines produced when flaking dead/dried material and which also affect the gluing characteristics of the boards. However, when used for plywood or laminated beams and joists, beetle-killed wood was rather assessed as an asset, having good glue bonding characteristics, although a high absorption rate led to an increase in glue consumption.

1. Have you ever taken into account the gluability of the beetle-killed lodgepole pine as a potential quality attribute when it needs to make decisions about using dead wood for OSB / Plywood / MDF?

Yes	No

2. If 'YES', taking into account the circumstances described above and based on other knowledge you have on this topic, how do you assess the degree of importance the gluability has on using beetle-killed timber for OSB / Plywood / MDF?
Please consider the live wood as a reference point.

-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5

Liability <<< --------- << --------- < No importance > --------- >> --------- >>> Asset
(Live timber)

3. Could you describe the reasons you had in your selection? Which are the product's attributes mainly affected by gluability? (e.g. strength, recovery, etc.)

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Wood product: OSB / Plywood / MDF

Overall suitability of beetle-killed timber

Recent studies have shown that some characteristics of the beetle-killed wood could be useful from various perspectives, especially from the economical point of view. When assessing the suitability of the dead wood for products the judges' judgments vary, depending on the knowledge they have on the topic, and the perspective they use when doing the assessment. Nevertheless, depending on specificity of each product, dead wood could be assessed differently in terms of suitability for a certain product.

1. Imagining a scale from -5 (the less suited) to +5 (the most suited) how would you assess the overall suitability of the beetle-killed timber for OSB / Plywood / MDF?
Please consider the live wood as a reference point.

-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5

Less suited <<< -------- << -------- < No influence > -------- >> -------- >>> Most suited
(Live timber)

2. Which of the wood properties (attributes) mentioned in this questionnaire has the highest weighting value (from your point of view), affecting the most the way you have made your decision in assessing the overall suitability of the dead wood for OSB / Plywood / MDF?

.....
.....

3. Are there other wood characteristics (not mentioned in this questionnaire) you have ever taken into account when making decision in assessing the suitability of beetle-killed timber for OSB / Plywood / MDF?

.....

Position/Location:

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